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Waychinicup Estuary, Western Australia: the influence of freshwater inputs on the benthic flora and fauna

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Abstract

Waychinicup Estuary (south-western Australia) is dominated by tidal and swell exchange with the ocean and receives seasonal, but low, freshwater inflows. The estuary was surveyed in September 1995 to determine the significance of freshwater inflows to its ecology and to provide a detailed inventory of benthic flora and fauna because, like other estuaries, Waychinicup may come under pressure for diversion of inflows to meet demand for potable water.

Gradients detected in benthic flora and fauna, sediment grain size and organic content, and water quality, were related to distance from the river mouth. Sediments closest to the river mouth had a higher organic content and a higher percentage of <63 µm particles. These areas had a low water clarity (SDD = 0.6m). Further from the river, the sediments became less organic and coarser, and water clarity increased (SDD >7 m). We hypothesise that biotic gradients in the estuary are determined by freshwater inflow, principally through its contribution of fine and organic sediments, and less so through its effect on salinity. These sediments are prone to resuspension, reducing water clarity, limiting plant growth and providing a niche for euryhaline, low light-adapted macroalgae and a polychaete-dominated infauna in the upper estuary. Change in sediment type, increase in water clarity and increasing salinity produces a shift to a diverse macroalgal and seagrass community, and an amphipod-dominated benthic fauna in the lower estuary.

Despite the dominance of oceanic exchange in the estuary, freshwater inflow is a key determinant of the composition and distribution of biota. Any significant reduction in freshwater inflow is likely to cause a change in water quality and biota; the system would have lower organic inputs, become clearer, and the plant and animal assemblages currently found in the upper reaches of the estuary may well be lost.

Introduction

The south coast of Western Australia has a diverse array of estuaries and coastal lagoons, ranging from those permanently open to the ocean through to some which are permanently closed. Cumulatively, as well as indvidually, these systems have enormous ecological, scientific and educational value. Like many ecosystems, however, these estuaries and coastal lagoons face potential threats. Among the most serious of these is the increasing demand for potable water supplies that accompanies recreational activities and tourism developments adjacent to estuaries. One means of meeting this demand is damming of the small rivers which feed the estuaries, and most at risk are those estuaries with relatively pristine catchments and reliable flows of freshwater.

Estuaries are characterised by highly variable ecological conditions due to the mixing of marine and fresh water. The stress this places on estuarine biota is a major determinant of the biotic community structure and leads to gradients in both floral species diversity (Doty & Newhouse 1954; Munda 1978; Josselyn & West 1985; Montague & Ley 1993) and faunal species diversity (Jones *et al.* 1986; Montagna & Kalke 1992) related to salinity gradients. Changes to the freshwater inflow regime may alter the complex biophysical relationships and are likely to have significant implications for estuarine biotic distribution.

While Waychinicup Estuary is not at all typical of other estuaries in the region, it does typify those estuaries most at risk of disturbance due to the future demand for freshwater. It is located close to significant demands for freshwater (the major urban centre of Albany is only 44 km to the west while nearby Cheyne Beach and the Two Peoples Bay Nature Reserve are increasingly used by tourists who require freshwater). Coupled with this, Waychinicup Estuary has a relatively reliable streamflow of potable water from a largely undisturbed catchment.

The role of freshwater inflow into Waychinicup Estuary was examined in relation to the benthic flora and fauna, and water quality parameters. The estuary itself is only about 1300 m in length and over half of this length is less than 2 metres deep. The system is well flushed by tidal and swell action and riverine input is small in comparison to the degree of oceanic exchange. Thus, it might be easy to dismiss the significance of relatively small inputs of freshwater as a determinant of biotic composition. However, we show that freshwater inputs are significant in this regard, but not through the simple effect of salinity variation.

A further objective of the study was to provide a baseline inventory of benthic biota in the estuary. The highly marine nature of this estuary also suggests that the benthic flora within the estuary may serve as a useful indicator of benthic flora in adjacent marine areas. Despite increasing threats to the estuaries of the south-west, there is a noticeable absence of comprehensive baseline data, apart from the preliminary inventories by Hodgkin & Clark (1988a,b, 1989a,b, 1990a,b).

Methods

Study area

Waychinicup estuary is located on the southern coast of Western Australia (34° 54' S 118° 19' E; Fig 1), approximately 44 km east of Albany. The area has warm summers and cool winters, and receives approximately 750 mm rainfall per annum.

The estuary is unique in the region. It is the only estuary with steep rock shores along most of its 1300 m length. Rocky headlands maintain a wide opening to the ocean, allowing relatively undampened influences of oceanic swells and tides and maintaining permanent exchange with the ocean. The Waychinicup River, the estuary's only riverine source, has a catchment of 145 km^2 of which 41% has been cleared (Hodgkin & Clark 1990b). The lower valley of the Waychinicup River and the Waychinicup Estuary are both within the Waychinicup National Park.

Data were collected on two visits to the estuary, on 2 September and 18 September 1995. Biotic and physico-chemical variables were examined on each occasion.

River flow

Total monthly stream records for the period 1970-1995 were obtained for the Waychinicup River Gauging Weir (# 602031) from the Water and Rivers Commission of Western Australia. These data were analysed to provide total monthly, winter and annual stream flow volumes and long-term average winter and annual flow volumes.

Macroalgae and seagrass

Nine transects were established at intervals along the length of the estuary as well as individual quadrat samples at the head of the estuary where the narrowness of the estuary did not allow transects (Fig 1A). The cover and composition of macroalgae and seagrass were recorded in quadrats (0.25 m^2) at 10 m intervals along the transect. Where transects occurred on areas of rocky granite and steep sides, quadrats were also taken at depth intervals. Data on seagrass distribution was supplemented by spot dives. All samples were identified to the lowest taxonomic level possible using keys of Huisman & Walker (1990) and Womersley (1984, 1987, 1994).

Patterns in macroflora assemblages were examined using the multivariate statistical analysis package PATN (Belbin 1993). All analyses were based on a presence/absence data matrix recorded for each quadrat using non-hierarchical allocation (Belbin 1987). Allocation was conducted following a Bray & Curtis association measure. This was selected as a dissimilarity measure since it is the most accepted measure used for ecological data (Faith *et al.* 1987). A radius of 0.6 was selected to define groupings in the allocation.

Benthic invertebrates and infauna

The presence and abundance of benthic invertebrate fauna was determined along three transects (Fig 1A). Three replicate core samples (120 mm diameter and 10 cm deep) were randomly taken from within the first, central and last 0.25 m of the transect. Core samples were sieved (1.0 mm) on location and preserved with buffered seawater formalin solution.

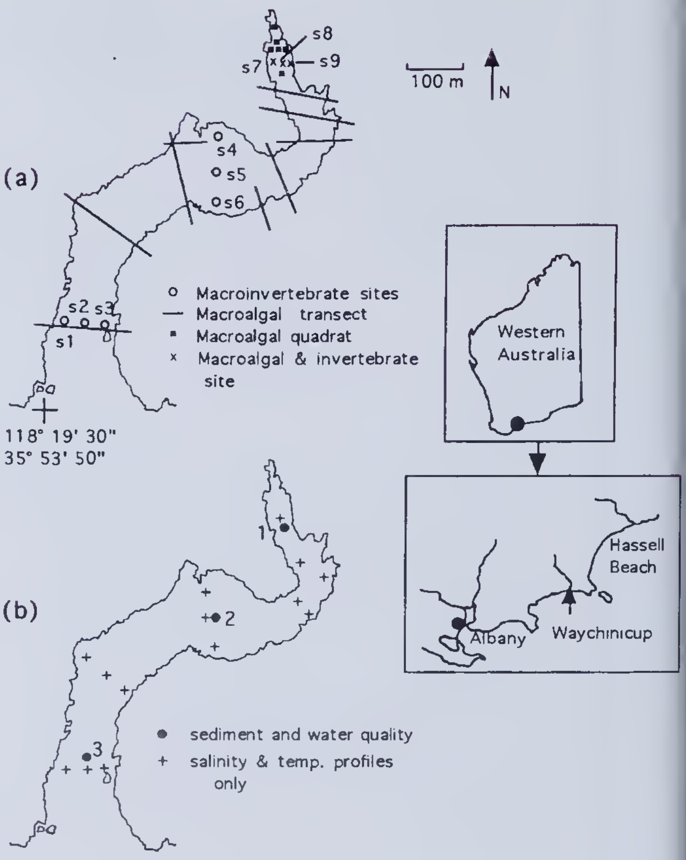

Figure 1. Sampling site locations for (A) benthic flora and macroinvertebrates and (B) sediments and water quality profiles in Waychinicup Estuary.

Material retained on the sieve was flooded in a tray to sort for invertebrates. One observer spent 15 minutes picking out any visible invertebrates from each sample. Then, a second observer spent five minutes on the same sample to check for any overlooked organisms. This standardised processing was intended to reduce observer bias and to impose a common effort on each sample. Invertebrates were identified to the lowest taxonomic level possible using Brusca & Brusca (1990), Wells & Bryce (1984, 1988), Hutchings (1984) and Shepherd & Thomas (1982, 1984).

PATN was used to explore patterns in infauna assemblages, based on a species abundance data matrix recorded for each replicate (core). Classification of the replicates following the Bray & Curtis association was conducted by flexible UPGMA, using a beta value of zero. Species groupings were determined by a two-step association measure prior to a flexible UPGMA. Quadrats were also ordinated in two dimensions following Bray & Curtis association, using non-metric multidimensional scaling.

Sediment sampling

Sediment grain size and organic content were sampled at three sites on a longitudinal transect in the centre of the estuary (Fig 1B). At each site, three replicate sediment cores were collected to a depth of 2 cm using 50 mm perspex corers.

Sediments were weighed then dried for 82 hours at 75 °C. Organic content was determined by combusting samples for two hours at 550 °C. Samples were then re-wet with deionised water and allowed to stand for two hours before wet-sieving through a 63 µm sieve. Water and sediment passing through the sieve were transferred into 10 mm centrifuge tubes and centrifuged for 15 minutes at 1800 rpm. The supernatant was removed and the remaining pellet of sediment was placed into a crucible and dried at 75 °C to determine the dry weight of the <63 µm fraction.

A subsample of each <63 µm sediment sample was combusted for one hour at 950 °C to determine the calcium carbonate ($CaCO_3$) content. Complete burn-off of $CaCO_3$ was verified by calculating the reduction in mass of $CaCO_3$ standards combusted with the samples. The $CaCO_3$ mass was used as an indication of fine particulate origin, with low content being interpreted as indicating a greater likelihood of terrigenous origin.

The mean proportion of organic matter and <63 µm fraction recorded for each site was compared by analysis of variance (ANOVA). Separate one-way ANOVAs were conducted for each, using arcsine-transformed data, followed by Fisher's PLSD pairwise comparisons (Zar 1984).

Water quality

Horizontal and vertical salinity profiles were recorded along the length and width of the estuary (Fig 1B), using a Yeo-kal Hamon Salinity-Temperature Bridge (MKII Model 602). Surface and bottom readings for temperature and dissolved oxygen (DO) were taken using a Yeo-kal Dissolved Oxygen/Temperature Model 630 meter. Light penetration was recorded using a Secchi disc.

Surface and bottom water samples were collected during each visit to the estuary, at three sites (Fig 1b). Bottom water samples were taken using a vanDorn bottle. Filtered (GFC 0.45 µm) samples were analysed for nitrate and nitrite, ammonia and orthophosphate using a Hach DR 2000 spectrophotometer, as per the cadmium reduction, salicylate, and ascorbic acid methods respectively (Anon 1989).

Results

Stream flow

Monthly, winter and annual streamflow for Waychinicup River are shown in Fig 2. Monthly flow was highly variable with the majority of flow occurring in the winter (June-September) period. Average annual flow (1970-1995) was 9.15 10^6 m^3, while the average winter flow over the same period was 6.02 10^6 m^3. The recorded winter flow in 1995 was 1.88 10^6 m^3, or only 31 % of the long-term average winter flow volume and the third lowest flow on record. However, interannual variation was high and the long-term average was greatly enhanced by the high flows in 1978 and 1979. Eleven years (44 % of recorded winters) had flows of less than 3 10^6 m^3 indicating that low flow years are not rare. The following results are probably indicative of the lower flow years.

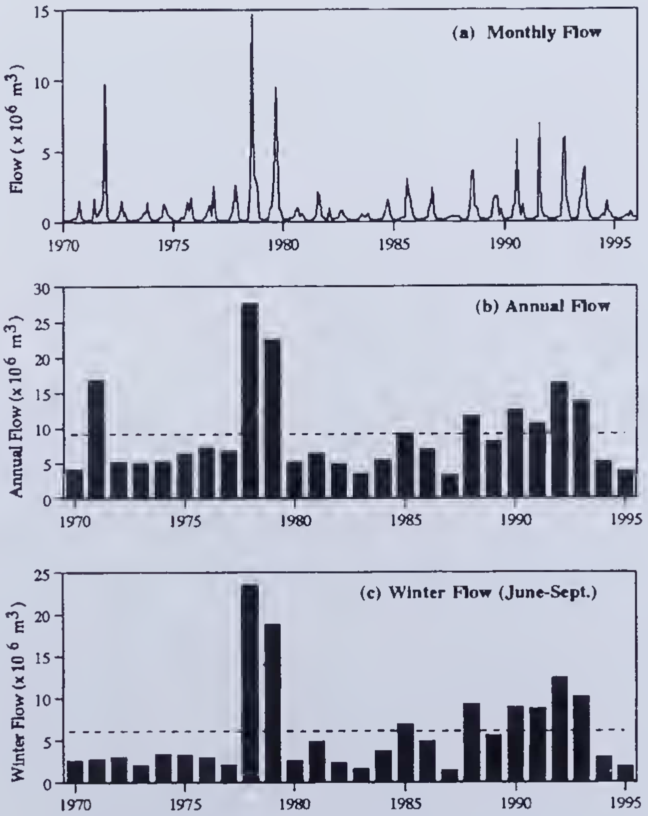

Figure 2. River flows for the Waychinicup River, 1970-1995. Dashed lines indicate the 1970-1995 average.

Physico-chemical variation

All of the measured variables showed detectable changes clearly associated with increasing distance from the river mouth.

There were both vertical and horizontal variations in salinity through the estuary with surface salinities consistently lower than bottom salinities (Fig 3). In September, stratification was greatest at the river mouth and least at 350 m from the river mouth where water depth was only 1.25 m. Surface salinity varied from 21.6 ppt at the head of the estuary to 33.9 ppt at the seaward mouth (Fig 3). Bottom salinity readings showed a smaller range of variation, from 27.4 ppt at the head of the estuary to 35.6 ppt in the lower reaches.

Surface temperatures ranged from from 14.7 °C at near the river mouth to 16 °C at 810 m and 1070 m from the river mouth respectively (Fig 3). Similarly, bottom temperature readings increased from 14.9 °C at site 1 to 16.2 °C at site 13. Temperature stratification was evident throughout the estuary, though only marginally so at 400 m from the river mouth.

Oxygen concentrations were consistently high throughout the estuary (Table 1; corresponding saturation values ranged between 94 - 102 %) with only minor spatial differences.

Variations in the concentrations of dissolved inorganic nitrogen (ammonia, nitrate+nitrite) and phosphorus (orthophosphate) were similar on both sampling dates, and so only data for 18/9/95 are shown in Table 1. Only orthophosphate showed a clear spatial variation, with very high concentrations near the river mouth and low concentrations elsewhere. The concentration of inorganic nitrogen varied negligibly through the estuary. There was noticeable stratification of orthophosphate in the upper reaches of the estuary (site 1) with the upper, less saline layer having almost four times the concentrations of the bottom waters. Corresponding to the variation in orthophosphate concentrations was a gradient in N:P ratios of the water column. The upper and middle estuary had ratios less than 16:1 and so could be classified as potentially N limited waters. It must be emphasised that these values are for a single sampling occasion at a time of low flow.

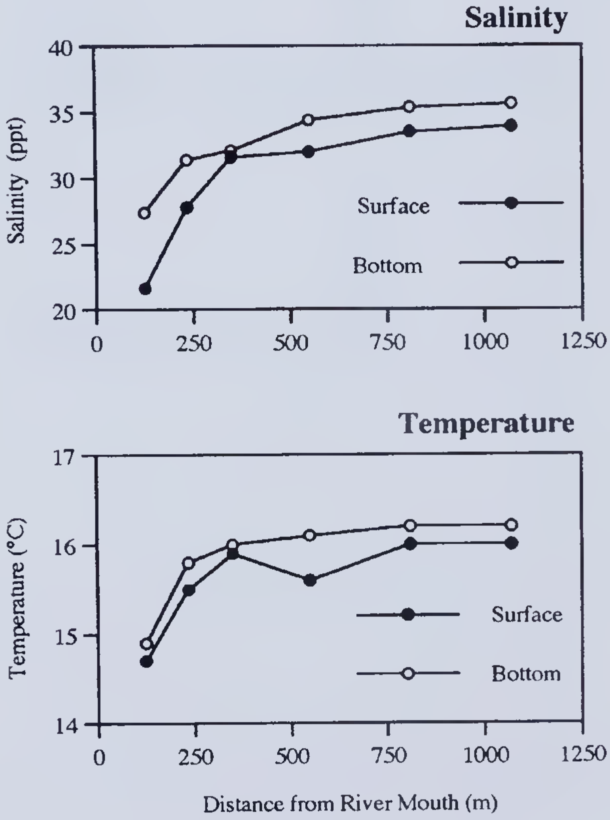

Figure 3. Water column salinity (top) and temperature (bottom) for surface and bottom water in Waychincup Estuary, September 1995.

Table 1

Nutrient concentrations in Waychinicup Estuary on 18 September 1995. N:P ratio is for dissolved inorganic ions.

NUTRIENT		Site 1	Site 2	Site 3
PO_4-P (mg L^{-1})	Surface	0.11	0.00	0.01
	Bottom	0.03	0.02	0.02
NO_3 -N (mg L^{-1})	Surface	0.07	0.08	0.07
	Bottom	0.03	0.03	0.03
NH_3 -N (mg L^{-1})	Surface	0.00	0.00	0.01
	Bottom	0.00	0.00	0.00
N:P Ratio	Surface	0.6	16	8
	Bottom	1.0	1.5	1.5
O_2 (mg L^{-1})	Surface	8.2	7.0	8.2
	Bottom	8.7	7.3	8.3

Sediments and light attenuation

As with the water column parameters, the sediment characteristics showed a clear gradient corresponding to distance from the river mouth. Mean organic matter content decreased with increasing distance from the river mouth (Table 2). The variation between sites was significant (ANOVA, $P < 0.05$; data arc-sine transformed). Site 1 had a significantly higher percentage organic matter than site 2 ($P = 0.02$, Fisher's PLSD) and site 3 ($P < 0.01$), but sites 2 and 3 were not significantly different. The greatest variation was observed at site 2, which supported a seagrass meadow.

Table 2

Mean (± standard deviation, n = 3) of sediment characteristics, Secchi disc depth and water depth in Waychinicup Estuary. Sites 1, 2 and 3 were 125 m, 550 m and 1070 m from the river mouth respectively. Sediment data are the transformed values derived from percentage by weight data.

Parameter	Site 1	Site 2	Site 3
Organic matter (%)	13.4 ± 0.8	9.3 ± 2.5	7.8 ± 0.6
Grain size <63 µm (%)	18.0 ± 0.7	14.8 ± 2.9	12.1 ± 0.4
Secchi disc depth (m)	0.65	1.4	7.5
Water depth (m)	1.6	2.0	9.2

The above trends were also reflected in fine particle fraction (Table 2). Site 1, closest to the river mouth, had the highest fine particle fraction. The variation between sites was statistically significant (ANOVA, $P < 0.05$). Fisher's PLSD indicated significant differences between sites 1 and 3 ($P < 0.01$). The greatest variation was again observed at site 2, which supported a benthic seagrass community.

Secchi disc depths increased with increasing distance from the mouth of the river (Table 2) thus varying positively with temperature and sediment organic content and fine particulate fraction. Secchi disc depth in the upper estuary was 0.65 m or 40% of the water column depth. In contrast SDD was over 7.50 m or 80% of the water depth at the lower site.

Benthic flora

There were clear spatial patterns in the benthic plant assemblages through the estuary which again coincided with increasing distance from the river mouth and the gradient in physico-chemical parameters.

Forty species of macroalgae and five species of seagrasses were recorded in the estuary (Table 3). Fourteen groups of benthic flora were identified, falling into two broad categories; those on the estuary floor or those on the vertical rock walls. The distribution of 'estuary floor' groups showed a strong gradient of species change in the upper reaches of the estuary (Fig 4). Fine green and red algae were limited to the upper 80 m of the estuary, whilst a mixed algal assemblage dominated by *Cystoseira trinodis* was restricted to an area of hard substratum between 150 m and 300 m from the river mouth. Elsewhere, the substratum was muddy to sandy and supported seagrasses (Fig 4). The seagrasses *Posidonia australis* and *Heterozostera tasmanica* were widespread although their distribution was generally limited to areas further

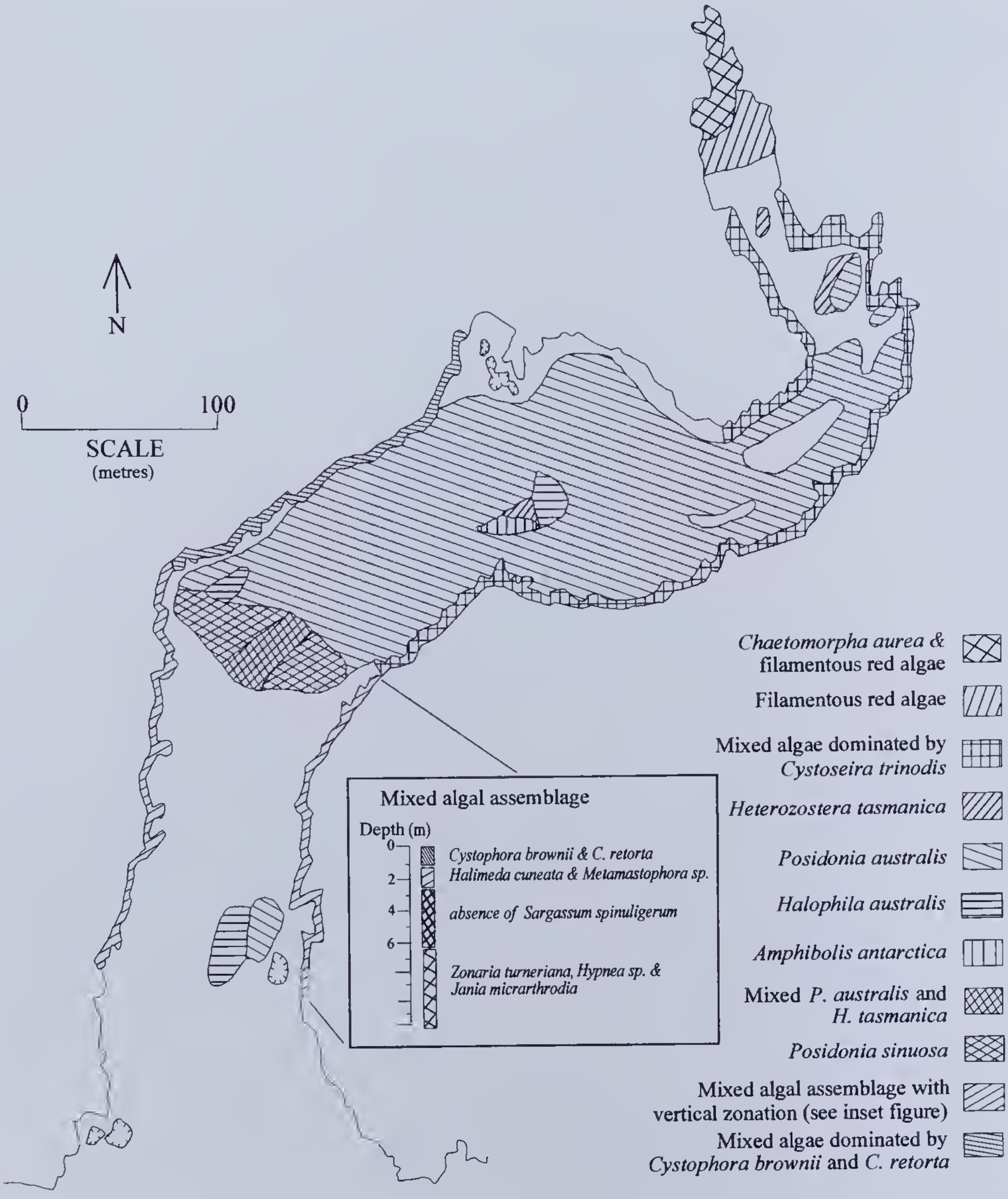

Figure 4. Distribution of benthic flora assemblages in Waychinicup Estuary, September 1995.

than 200 m from the river mouth. *Posidonia sinuosa*, a seagrass that is usually found in higher energy environments, was found only near the mouth of the estuary. Three other species, *Halophila australis*, *Heterozostera tasmanica* and *Amphibolis antarctica* occurred in small patches throughout the estuary.

The vertical rock faces in the lower reaches of the estuary supported a mixed algal assemblage dominated by brown and red algae. Allocation analysis indicated vertical zonation (Fig 4).

Benthic invertebrate and infauna assemblages

The two-dimensional ordination from pooled replicate data showed patterns in sites relating to location within the estuary (Fig 5). There were three clear groups, with all sites for each of the the upper, middle and lower estuary transects clustering together. The dendrogram from classification of all replicate data from the nine sites also reflected this pattern with the upper estuary sites (1, 2 & 3; 150 m from the river mouth) showing a high dissimilarity to other sites. A cut-off value of 0.96 (a very high degree of dissimilarity) produced five groups of sites with the three upper estuary sites clearly separating out as one group (Fig 5).

There was a shift from small crustacean dominated sites at the mouth of the estuary to sites dominated by polychaete worms in the upper reaches of the estuary (Table 4). The pattern of species shift shown by the classification and ordination analyses (Fig 5) corresponded well to the dominant sediment type at each site (Table 5).

Table 3

Benthic macrophyte species recorded in Waychinicup Estuary (September 1995) and their approximate distances from the river mouth. * indicates presence.

	metres from river mouth														
	5	30	60	80	100	120	160	210	270	360	510	610	650	810	1070
Chaetomorpha aurea	*		*	*											
filamentous red sp 1		*		*	*										
Heterozostera tasmanica						*	*	*	*	*				*	
Cystoseira trinodis							*	*	*	*	*		*	*	
filamentous red sp 2							*	*	*	*	*				
Sargassum spinuligerum							*	*	*	*				*	*
Posidonia australis							*	*	*	*	*	*	*	*	*
Colpomenia sinuosa								*	*		*				
Laurencia sp 1								*		*				*	*
Phloiocaulon spectabile											*	*			
Cystophora brownii												*	*	*	*
Cystophora retorta												*	*	*	*
encrusting red coralline sp 1												*	*		*
encrusting red coralline sp 2												*	*	*	*
Hormosira banksii													*	*	
Posidonia sinuosa														*	
Amphibolis antarctica														*	
Dictyopteris sp														*	
Chondria sp														*	
Laurencia sp 2														*	
Metagoniolithon radiatum														*	*
Halophila australis														*	*
Ecklonia radiata														*	*
Lobophora variegata														*	*
Sargassum distichum														*	*
Haliptilon roseum														*	*
Sargassum sp 1															*
Dictyosphaeria sericea															*
Cystophora sp															*
Caulerpa distichophylla															*
Amphiroa anceps															*
Halimeda cuneata															*
Phacelocarpus adopus															*
Metamastophora sp															*
Zonaria turneriana															*
filamentous red sp 3															*
Dictyota dichotoma															*
Hypnea sp															*
Sargassum sp 2															*
Sargassum tristichum															*
Cystophora monilifera															*
Jania micrarthrodia															*
Rhipiliopsis peltata															*
Lenormandia spectabilis															*
Stenogramme leptophylla															*

Discussion

The unique physical and hydrologic features of Waychinicup Estuary, which have been described above, are clearly reflected in its benthic flora. With over forty five species, Waychinicup Estuary has an exceptionally rich benthic flora. By comparison, the vast majority of other south coast estuaries are dominated by three species of benthic macrophyte, *Ruppia megacarpa*, *Polyphysa peniculus* and *Lamprothamnion papulosum* with its associated epiphytes (*e.g.* Hodgkin & Clarke 1989a,b, 1990).

The benthic flora of Waychinicup Estuary is predominantly a marine intrusion flora. The seagrasses in the system are typical of coastal marine areas not estuaries, and the macroalgal assemblages in the lower reaches are dominated by species typical of southern Australian marine flora (Womersley 1984, 1987, 1994). In this respect, the algal composition of the lower reaches recorded in this winter survey is likely to be a better representation of open coastal marine flora of the south coast than it is of other estuaries.

Table 4

Benthic macroinvertebrates recorded in Waychinicup Estuary (September 1995) and their approximate distances from the river mouth. (See Fig 1A for site locations). p = Polychaetae, mx = Maxillopoda, m = Malacostrata, g = Gastropoda, s = Sipunculada, o = Oligochaetae, b = Bivalva. 1 is < 250 m^{-2}, 2 is < 500 m^{-2}, 3 is < 800 m^{-2}, and 4 is > 800 m^{-2}.

Region:	Lower			Middle			Upper		
Site:	1	2	3	4	5	6	7	8	9
Lyssianassidae sp (m)	2								
Spio pacifica (p)	4	4	1				1	1	
maldanid sp 1 (p)	1	1							
Odontosyllis sp (p)	1	1	1	1	1				
Birubius sp (m)	1	1	1						
Paphies sp (b)	1		1	1			1		1
Tipimegus sp (m)	1		1	1					
Anthuridae sp (m)		1							
mysid sp 1 (m)		1							
Aricidea fauveli (p)		1	1		1	1			
Phallodrilus wellsi (o)		1	1			1			
amphipod sp (m)			1						
Austropheonoides sp (m)			1						
Oedicerotidae sp (m)			1						
Paradexamine sp (m)			1						
ostracod sp 1 (mx)			1						
Rhinothelepus setosus (p)			1	1					
Guernea endota (m)			2	1					
Golfingia sp (s)			1		2	1	1		
Leonnates sp (p)				1					
oligochaete sp (o)				1				1	
Bittium sp 1 (g)				3					
Bittium sp 2 (g)				1					
Spisula trigonella (b)				1		1	1		
Paratanais ignatus (m)				1		1	1		
Apseudidae sp (m)				1	1	1	1		
Caullierella sp (p)					2	1			
Capitella capitata (p)						1	2	4	1
maldanid sp 2 (p)					1				
Notomastus estuarius (p)					1		1		
Naineris grubei (p)					1		1	1	1
Leitoscoloplos bifurcatus (p)						1			1
Katyelsia rhytiphora (b)						1			
Tethygeneia nalgo (m)						1			
mysid sp 2 (m)									1
Total Species		19			23			12	

Notwithstanding the above, our results clearly indicate that other factors are important in shaping the distribution patterns in the upper reaches of the estuary. Salinity may be an important determinant of macroalgal distribution in Waychinicup Estuary, but in association with turbidity. Only two algal assemblages penetrated to the very head of the estuary. This trend of reduced diversity in the upper reaches of estuaries is often ascribed to salinity effects (McLusky 1989; Morrisey 1995) though in this case it appears to be a combination of both salinity and light attenuation. The fine green alga in the upper reaches (*Chaetomorpha*) is typically adapted to variable salinity regimes and better adapted to poor light conditions than larger brown and red algae (Lavery 1989). Other macroalgal groups in the upper and mid-estuary reaches showed a strong gradient of species changes, which may be due to factors other than light penetration. Not only did benthic plant groups change along a gradient of increasing salinity, but vertical groups also changed with increasing salinity. Although vertical species shift would be partly depth-related those groups that occurred at the water line must be able to tolerate, in addition to wave action, a relatively wide range of salinity given the freshwater lens that was evident at the time of this study.

All of our results suggest that freshwater inflow is a significant determinant of biological gradients in Waychinicup Estuary. This is despite the relatively small volume of inflow, its seasonality, and the degree of ocean exchange which is large. Thus while it might be argued that this system is in fact a simple river mouth with granite headlands, the parameters measured in this study clearly suggest it is, at least seasonally, a stratified estuary. In drawing this conlcusion, it must be stressed that the estuary was surveyed over a limited period in one of the lowest flow years recorded. While the conditions in the estuary therefore represent a 'snapshot', they were probably a conservative estimate of the role freshwater inputs play in the system. It is probable that the role of freshwater in

Table 5

Qualitative description of sediment characteristics in Waychinicup Estuary.

Location	Site	Sediment type
lower reaches	1 - 3	coarse sand/shell fragments
middle reaches	4	medium to coarse sediments; some organic matter
	5	fine to medium sediments; some organic matter
	6	medium to coarse sediments; accumulation of dead shells
upper reaches	7	fine mud and sands with fine organics and seagrass detritus
	8	fine muds/silt
	9	seagrass detritus over medium coarse sediment and shells

driving biological gradients will be greater in higher flow years.

There was a gradient in most variables that related to distance from the source of riverine inflow, indicating that during these flow conditions freshwater inflows are affecting several variables, not just salinity. In particular, freshwater inflow appears to influence sediment distribution with subsequent effects on water clarity and sediment characteristics which directly affect benthic floral and faunal distributions.

Three possible sources of fine sediment within Waychinicup Estuary are the inflowing river, the coast, and from the margins of the estuarine basin itself (Carter, 1988). The margins were considered to contribute the smallest proportion of fine sediment, however, due to the large area of granite rock bordering the estuary. Fine sediments of marine origin in the form of calcium carbonate (from organisms such as foraminiferans and the weathering of shell material) were eliminated from samples taken from all three sediment sampling sites, leaving only clays and silicas. Since organic matter had been removed, it can be concluded that the remaining fine sediments were predominantly introduced with freshwater inflow, and this appears to be supported by the gradient of decreasing proportion of fine particles with increasing distance from the river source.

The gradient in sediment characteristics in Waychinicup Estuary provides a range of microhabitats for benthic invertebrates. Richness and abundance of benthic invertebrate species appeared to be related to differences in microhabitats and in particular sediment characteristics. Furthermore, invertebrate assemblages varied not only between transects but also within transects, suggesting that sediment characteristic gradients also existed across the estuary, most likely the result of seagrass distribution modifying the longintudinal gradient of sediment type.

The salinity stratification was correlated with higher levels of nutrients in surface waters in the upper reaches of the estuary. High levels of phosphate were expected, given that the upper catchment of Waychinicup River is

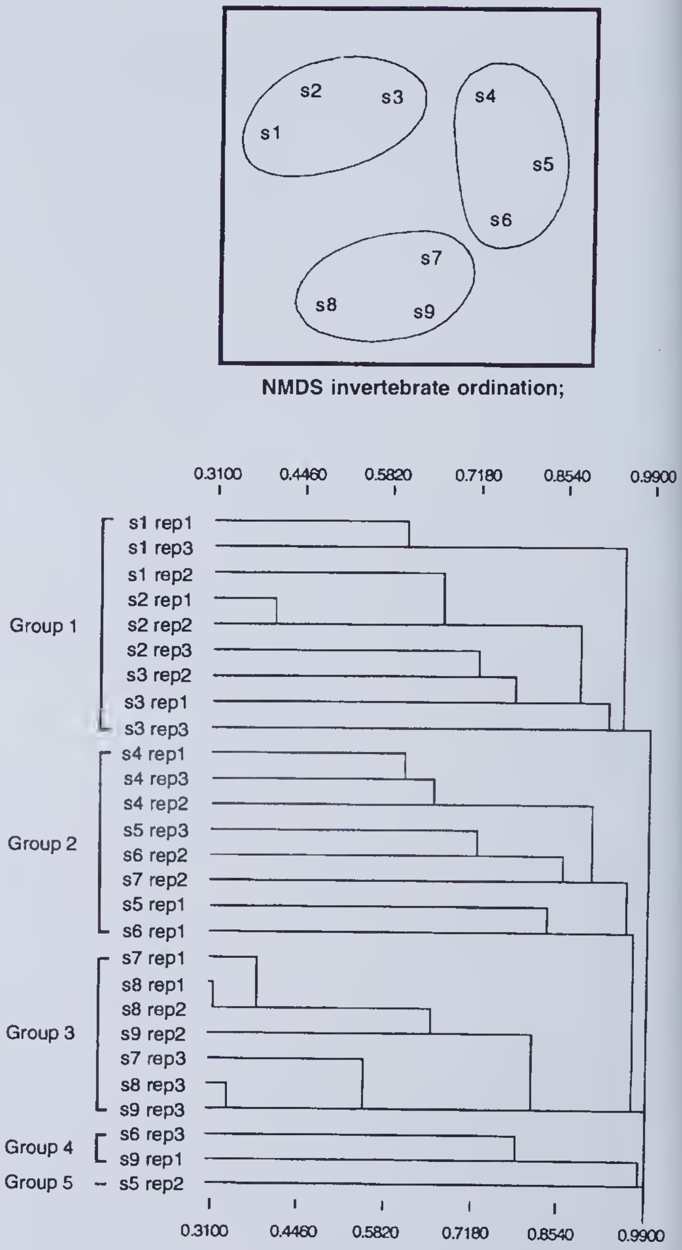

Figure 5. Ordination and associated dendrogram of sites and replicates based on the presence/absence of benthic macroinvertebrate fauna. See Fig 2 for site locations (s1 rep 1 = site 1 replicate number 1 *etc*).

cleared for agriculture, and this was indeed the case at the time of this study. The dissolved phosphate concentrations were comparable to those in highly eutrophic estuaries of south-western Australia (Lukatelich & McComb 1986). However, at the time of sampling a high degree of tidal exchange was evident as well as short term oscillations in the direction of flow due to incoming swells through the estuary mouth. Together with the degree of stratification, these exchange will significantly reduce nutrient accumulation, and the associated effects, within the estuary.

Management implications

It is clear that freshwater inflow into Waychinicup Estuary has a significant influence on the nature of the estuary. The results of the winter survey clearly emphasise the uniqueness of this estuary, and its ecological and conservation value. Within this very small inlet/estuary there is a clear gradation from an 'estuarine' to open marine flora which is not recorded for any other system along the south coast. Any diversion of freshwater inflows to this system would therefore impact its ecology. It can be easy to overlook the importance of a small, seasonal freshwater input to an inlet which is so obviously dominated by tidal and oceanic swell exchange. Yet, any significant reduction in freshwater flow would reduce particulate loads to the estuary and, subsequently, sediment characteristics and the distribution and composition of benthic biota. While seagrasses might extend further up the estuary, the coarser sediments and lower turbidity would produce a more homogenous flora and possibly exclude the benthic invertebrate assemblages associated with fine mud and silt. Finally, reduction in freshwater inflow may reduce the degree of stratification and enhance vertical mixing in the estuary.

In conclusion, there are expected to be changes to the nature of the estuary in the event that freshwater is dammed or diverted, but how important such changes would be depends on how the estuary is valued. Given the estuary's location within Waychinicup National Park, it is assumed that it would be a management objective to preserve it for its intrinsic values, and so any alteration in the nature of the estuary can only be regarded as undesirable.

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